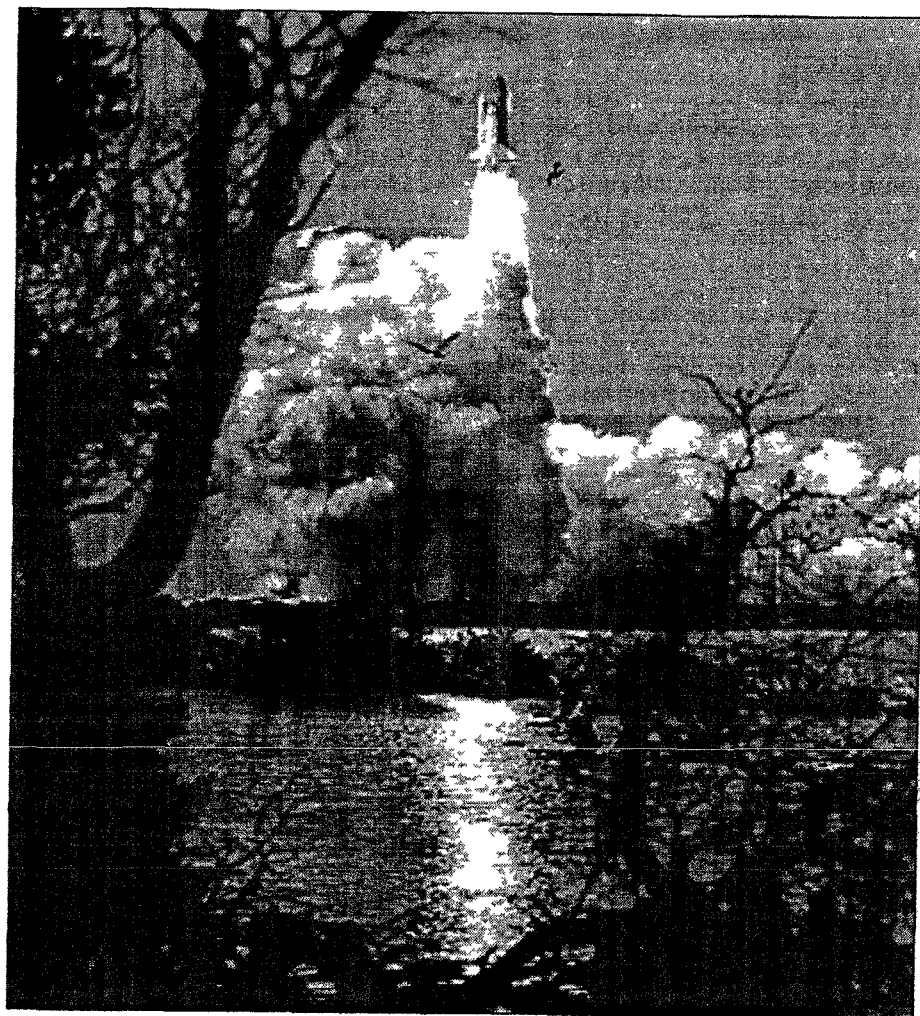




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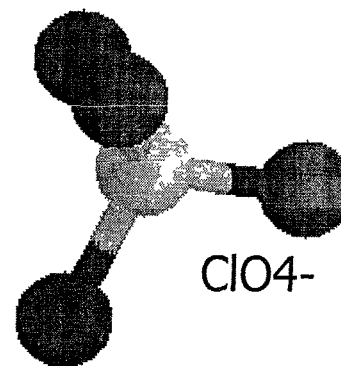
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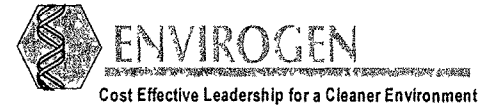
02M022003D

BIOREMEDIATION OF PERCHLORATE IN GROUNDWATER

Todd Webster, Ph.D.



PROBLEM STATEMENT



Perchlorate (ClO_4^-)

Use:	Perchlorate salts have been used extensively in DoD during last 5 decades as fuel oxidants in rockets.
Contamination:	Fuel replacement, manufacture, storage, rocket testing, has led to groundwater contamination in at least 14 states, including CA, NV, UT, TX. Total scope of contamination unclear.
Toxicology:	Perchlorate inhibits thyroid function and influences metamorphosis. Effects of low level exposure are uncertain. California action level is 18 ppb.
Characteristics:	Anion, low volatility, high water solubility, chemically stable, persistent in environment for years.
Remediation:	Traditional <i>ex situ</i> technologies (e.g., air stripping, carbon adsorption, filtration) are ineffective. Biological remediation is considered the most promising approach.

Perchlorate Manufacturers/Users

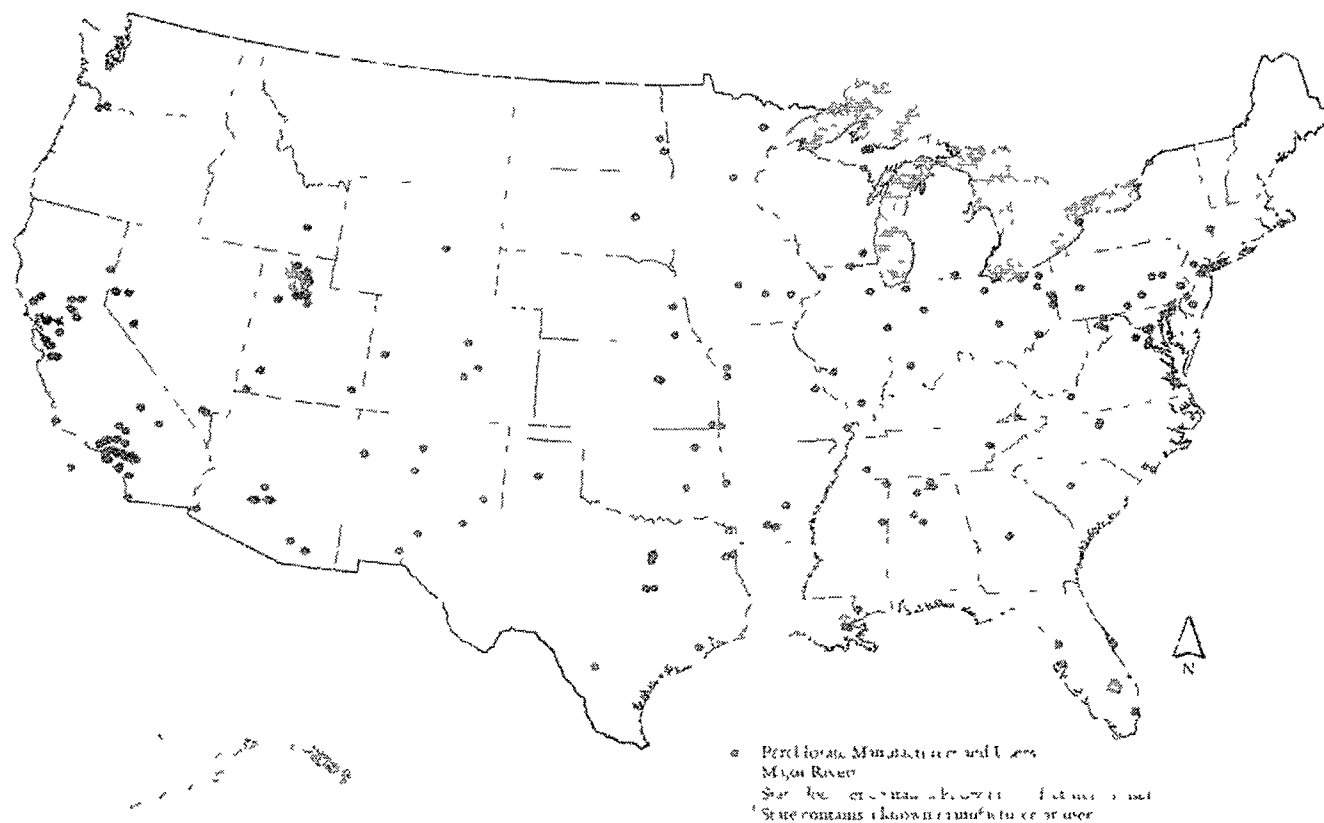
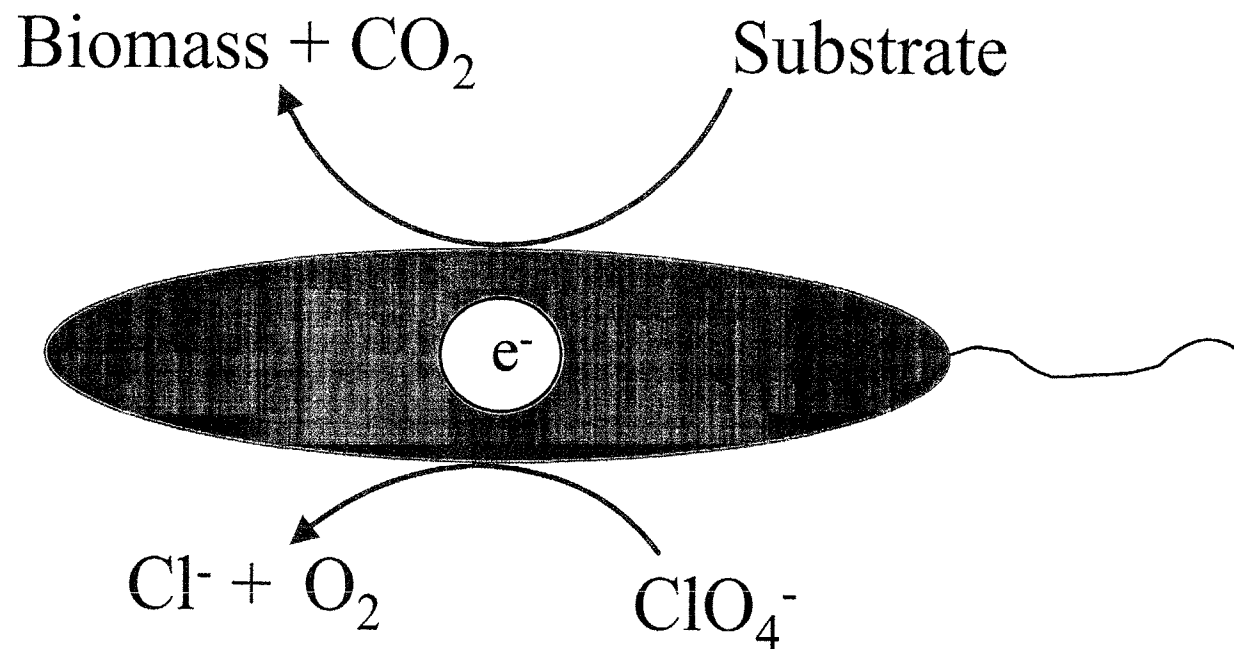


Figure 1-3. Locations of specific perchlorate manufacturers or users identified through responses to EPA Information Requests from current manufacturers (identifying shipments of at least 500 pounds in any year) and through investigations by state and local authorities (Mayer, 2001).

TECHNICAL BACKGROUND



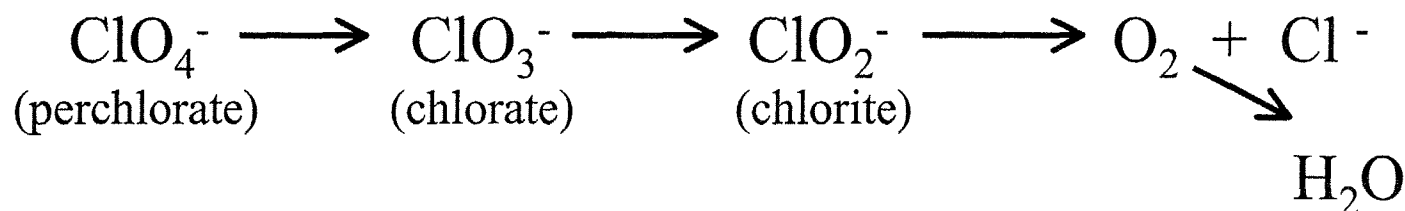
Biological Perchlorate Reduction



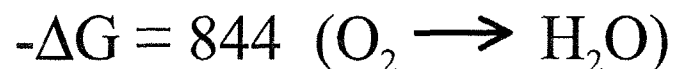
BIOLOGICAL PERCHLORATE REDUCTION



- ***Terminal Electron Acceptor:***



- ***Highly Favorable Reaction (kJ/mol acetate)***



- ***Several Microbial Isolates Reported***

Dechlorisoma JPLRND (Envirogen, 2000); Strain CBK (Bruce et al., 1999);

Strain perace1 (Herman et al., 1999)

Strain GR-1 (Rikken et al., 1996);

Wolinella succinogenes HAP-1 (Wallace et al., 1996)

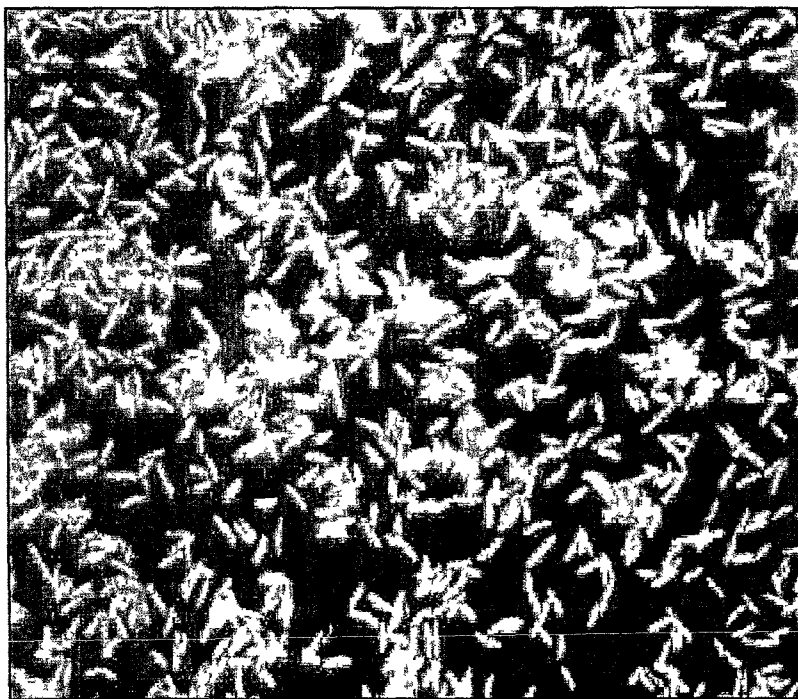
Ideonella dechloratans (Malvquist et al., 1994)

PURE CULTURE

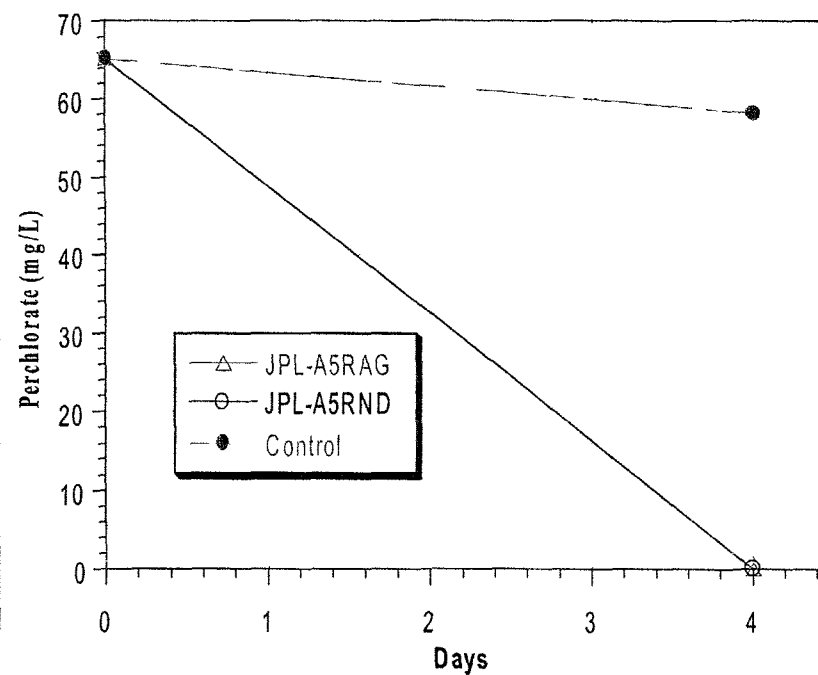


ENVIROGEN

Cost Effective Leadership for a Cleaner Environment



Perchlorate Degradation by Two Pure Cultures
Isolated from JPL Groundwater.



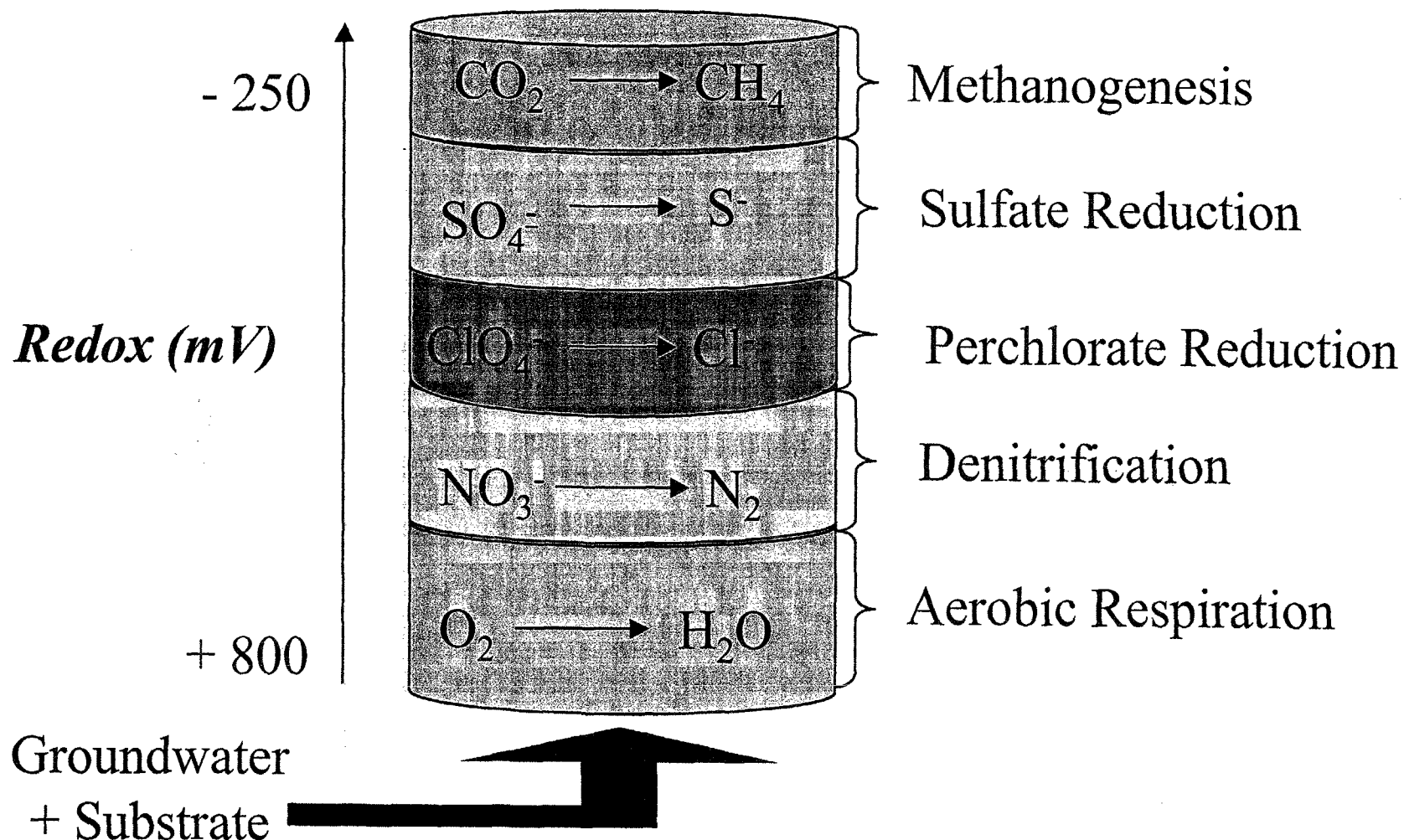
Dechlorisoma suilla JPL-A5RAG/JPL-A5RND

UTILIZATION OF ELECTRON ACCEPTORS



ENVIROGEN

Cost Effective Leadership for a Cleaner Environment



Biological Treatment

- ***Ex Situ* Treatment**

Fluidized Bed Reactor - Full Scale - (Envirogen/US Filter).

Suspended Growth Reactor - Full Scale - (USAF/ARA).

Fixed Film Reactor- Pilot Scale - (Penn State, UC Riverside).

- ***In Situ* Treatment**

Laboratory and Pilot Studies Show Promise for
In Situ Biostimulation (Envirogen/Geosyntec).

One Full-Scale System - McGregor NWIRP.

In situ bioremediation



ENVIROGEN

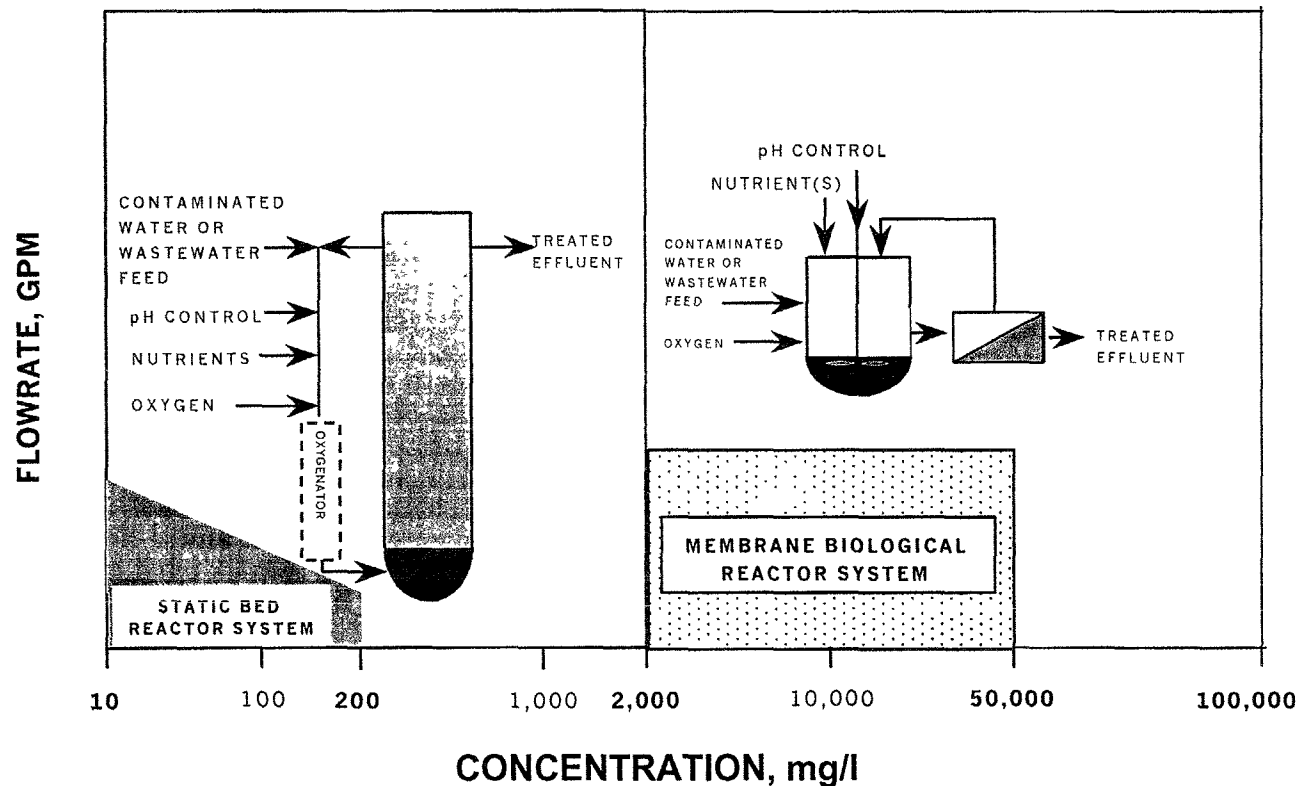
Cost Effective Leadership for a Cleaner Environment

EX SITU TREATMENT **FLUIDIZED BED REACTOR**

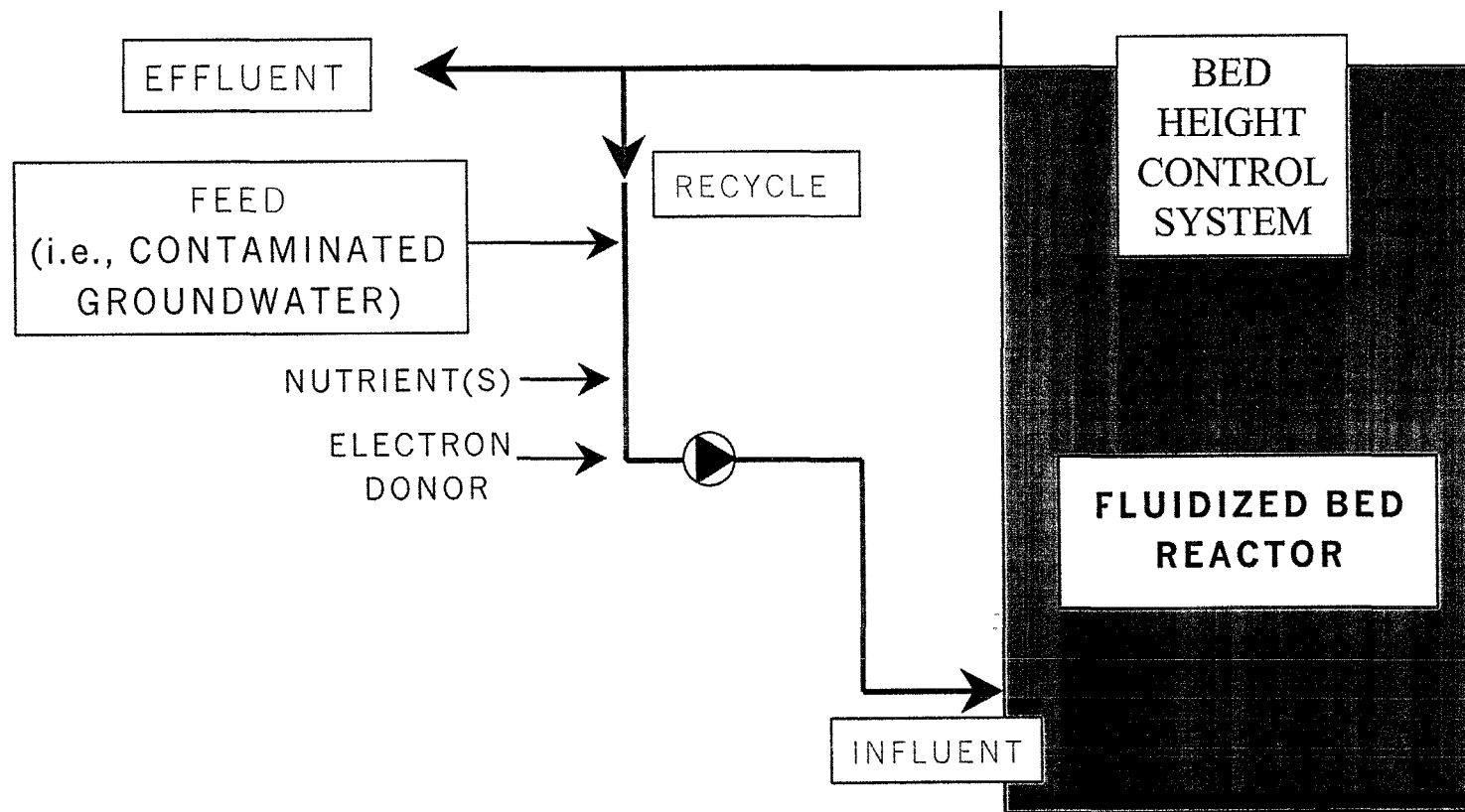
AEROJET

LHAAP

Bioreactor System Options for Treatment of Organic Chemicals



FBR Flow Schematic



*Generally carbon
light*



FBR Advantages

- High biomass concentration means long SRT and short HRT (287 - 35 m MT)
- High volumetric efficiency translates to compact system
- Simplicity of operation minimizes need for operator attention
- Small impact from changing feed conditions, as feed is combined with recycle before entering the reactor



Key Mechanical Components

- Device and method used to distribute influent flow to the reactor
- Device and method used to control the expansion of the fluidized bed due to biofilm growth
- Method to control electron donor dosage rate

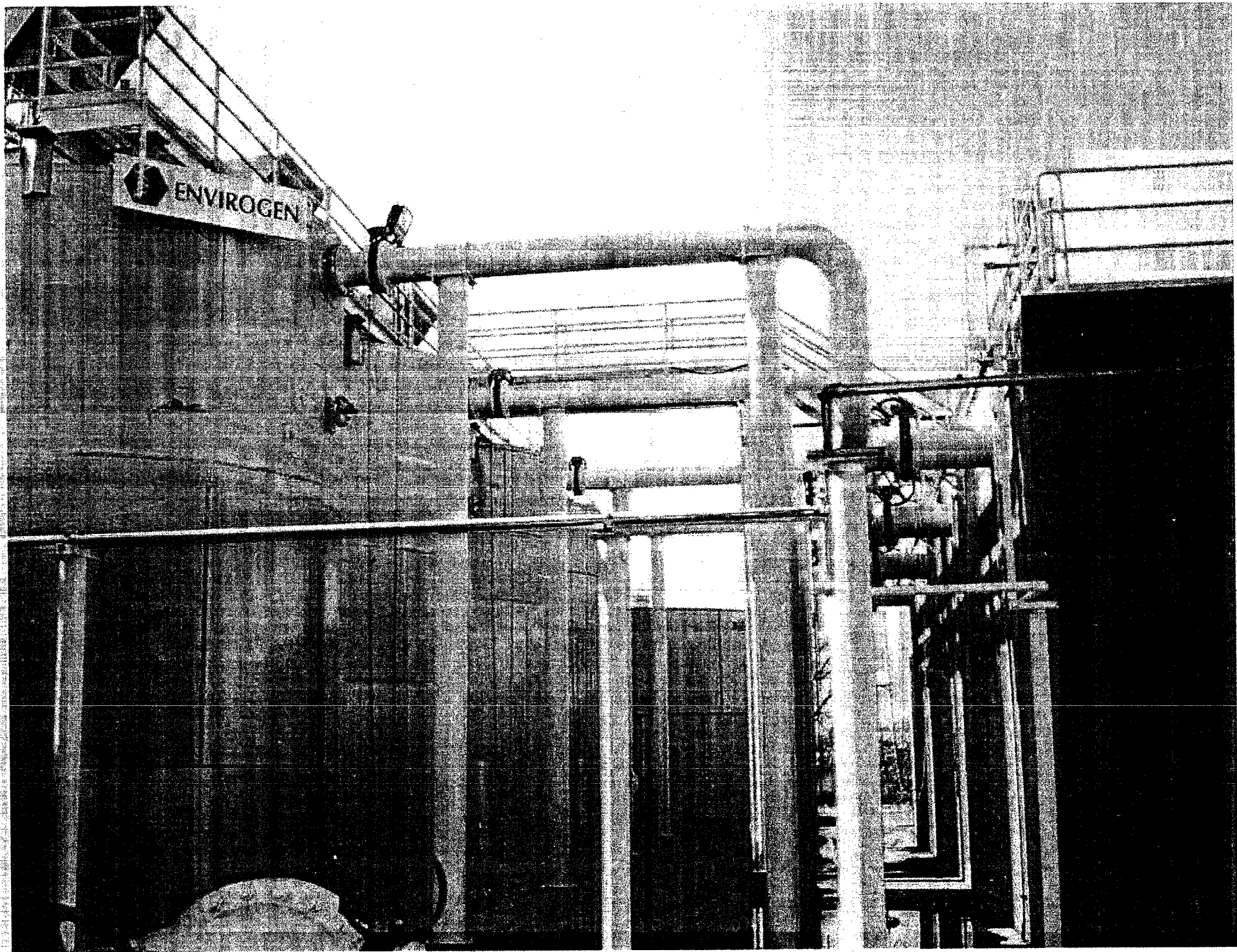


FULL-SCALE SYSTEM



Aerojet Facility - Rancho Cordova California

- FBR SYSTEM
 - 4 - 6 mg/L perchlorate
 - 4,000 GPM flow rate
 - Four 14 ft diameter units
 - Ethanol as electron donor
 - GAC media

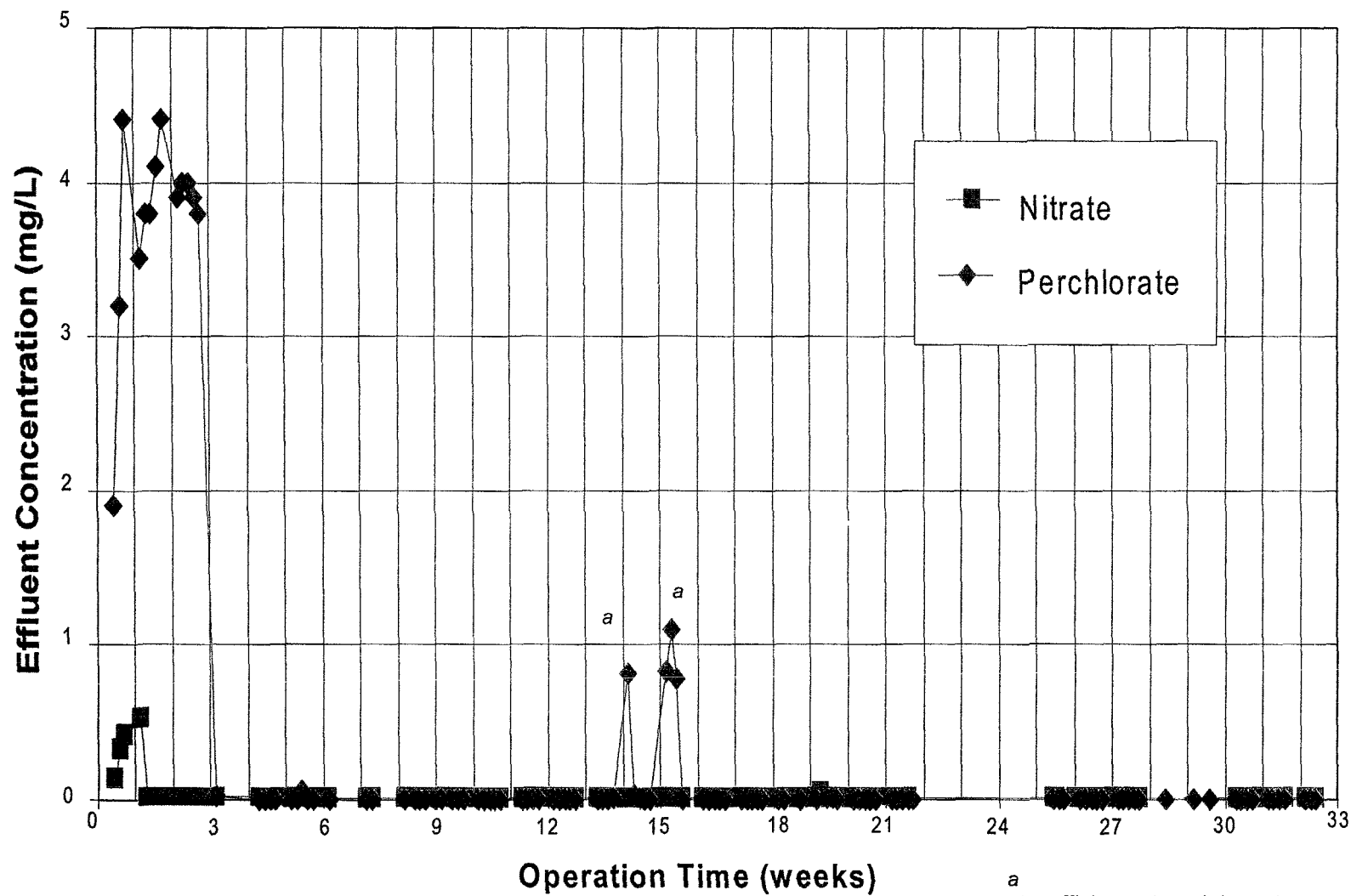


FULL-SCALE FBR PERFORMANCE



ENVIROGEN

Cost Effective Leadership for a Cleaner Environment

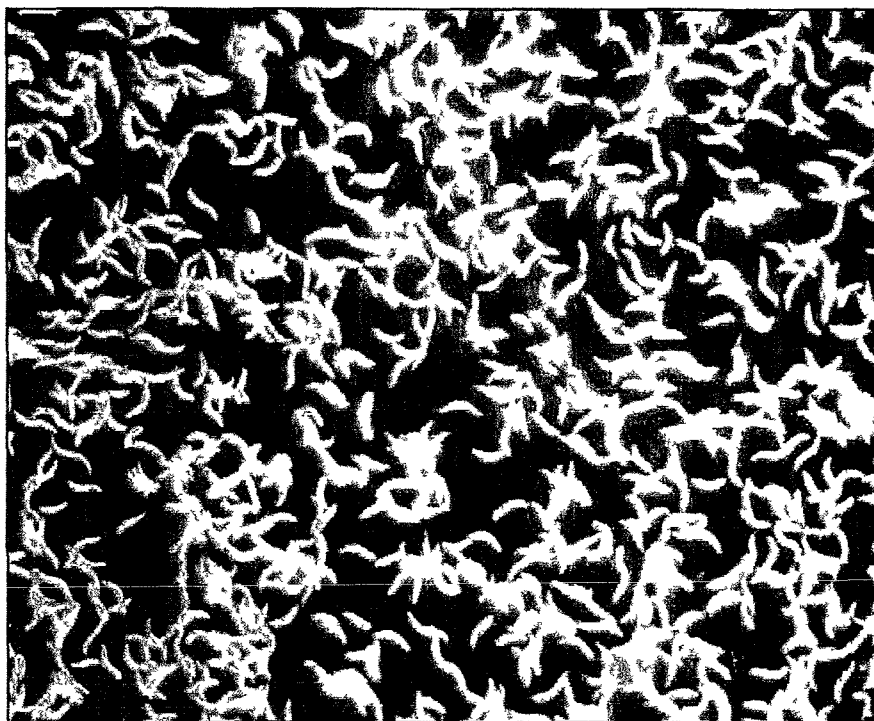


^a
Insufficient ethanol dose during system tests.

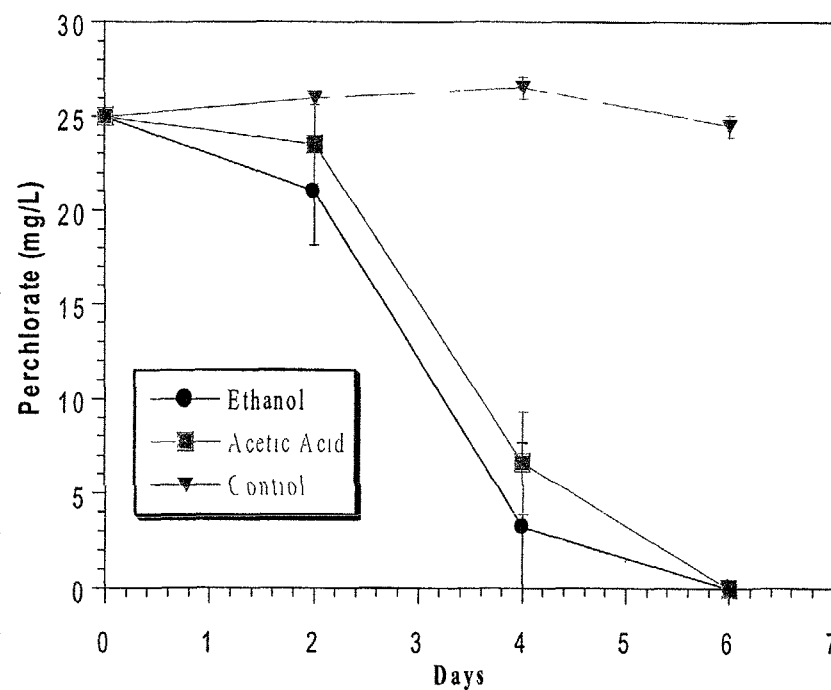
AEROJET REACTOR CULTURE



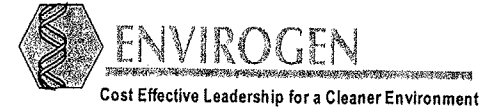
Dechlorospirillum sp. FBR2



Perchlorate Degradation by FBR-2 Enrichment Culture



FULL-SCALE SYSTEM



Longhorn Army Ammunition Plant - Karnack, Texas

- FBR SYSTEM

- 15 mg/L perchlorate
- 50 gpm flow rate
- One 5 ft.diameter unit
- Acetic acid
- GAC media





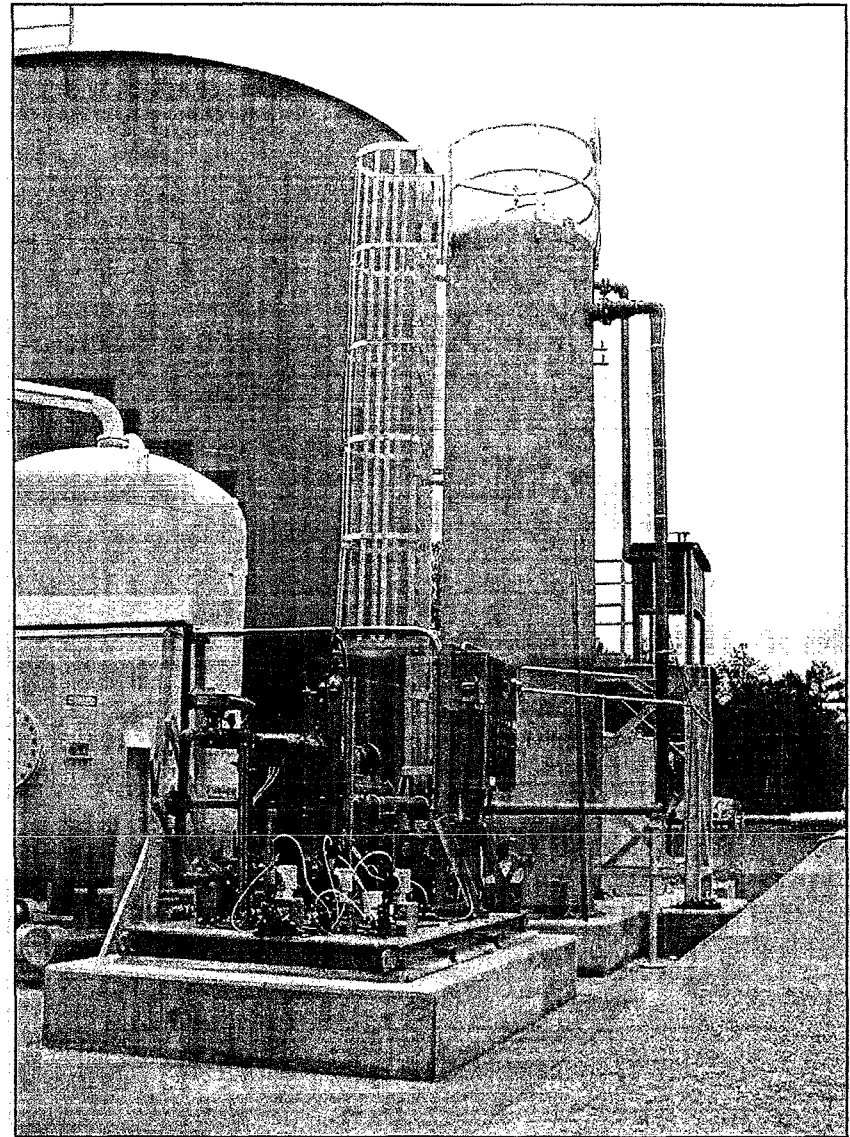
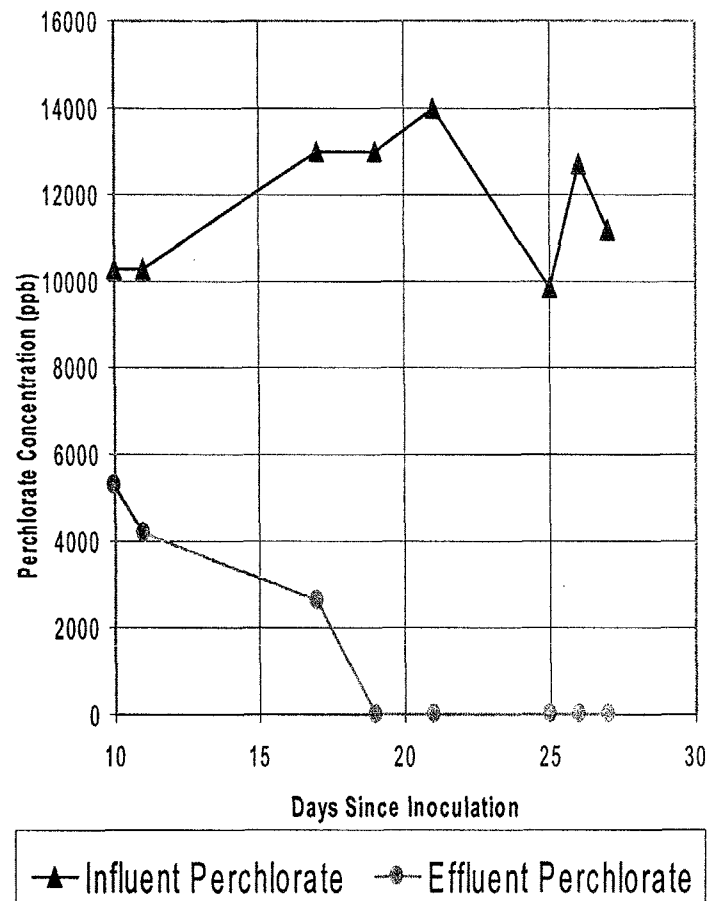
SYSTEM PERFORMANCE

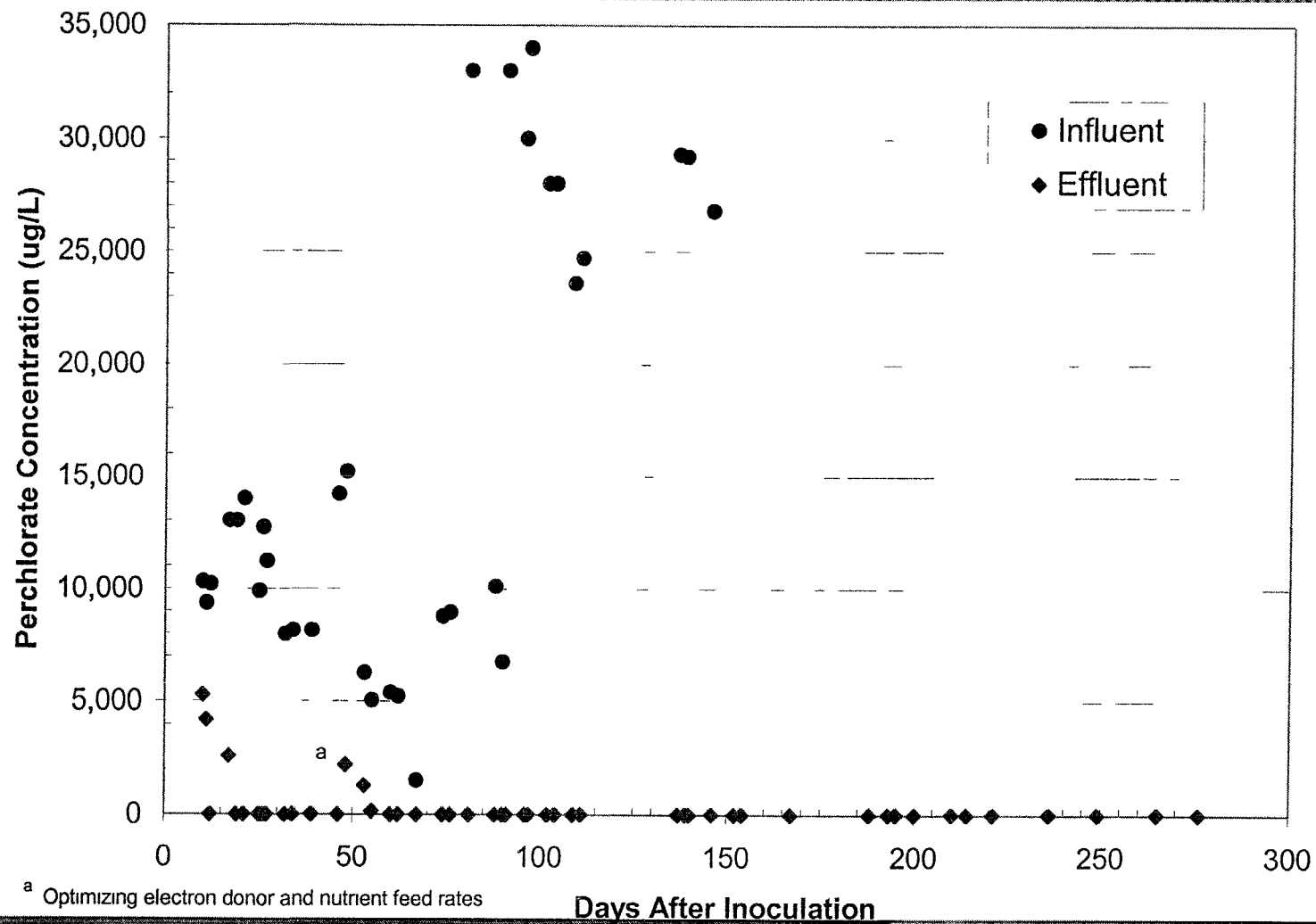


ENVIROGEN

Cost Effective Leadership for a Cleaner Environment

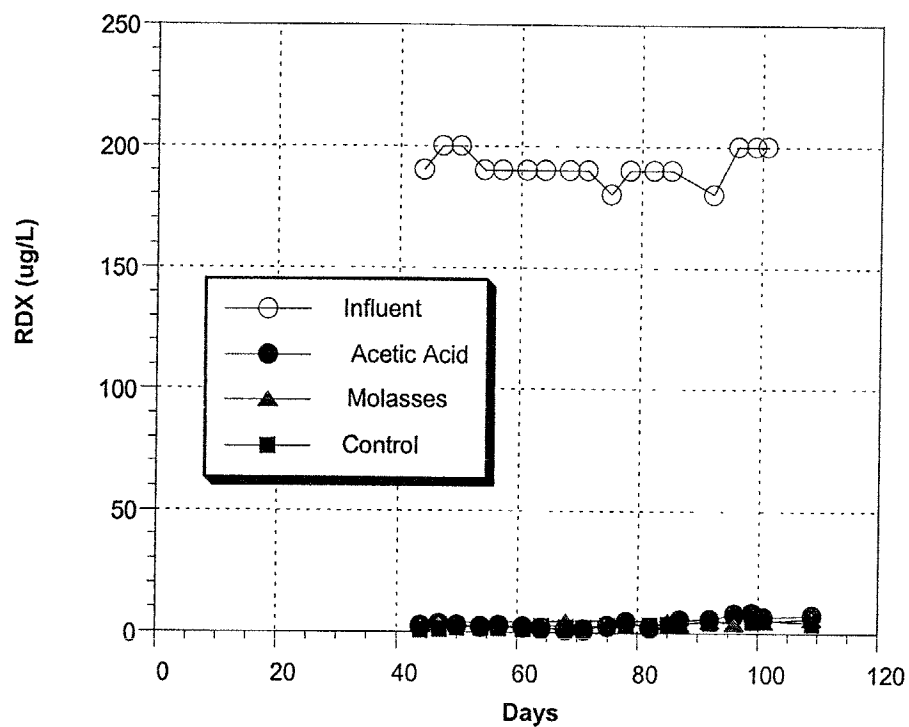
Longhorn Army Ammunition Depot
ENVIROGEN FBR System Performance



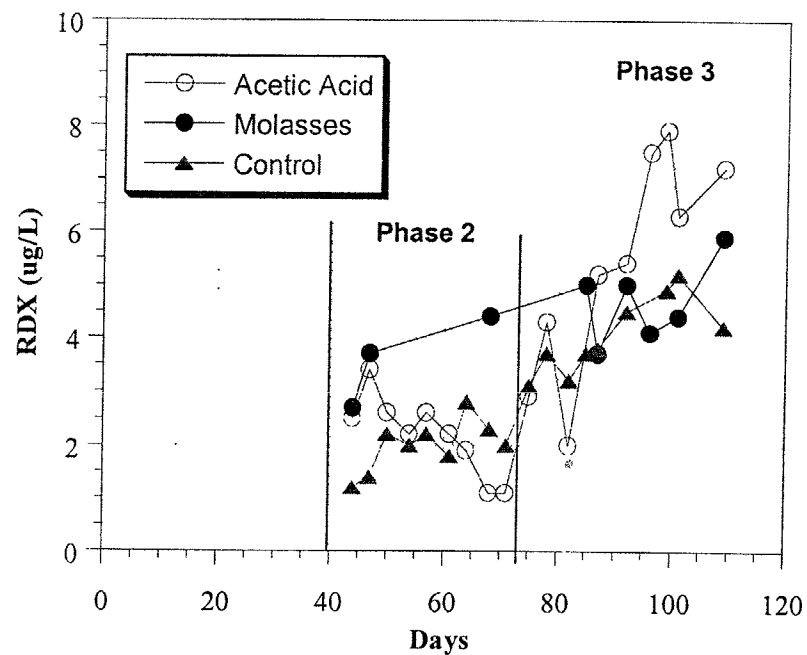


Results - RDX

Influent and Effluent Levels of RDX in FBRs Receiving
Acetic Acid, Molasses, or No Substrate



Close-Up of RDX Data

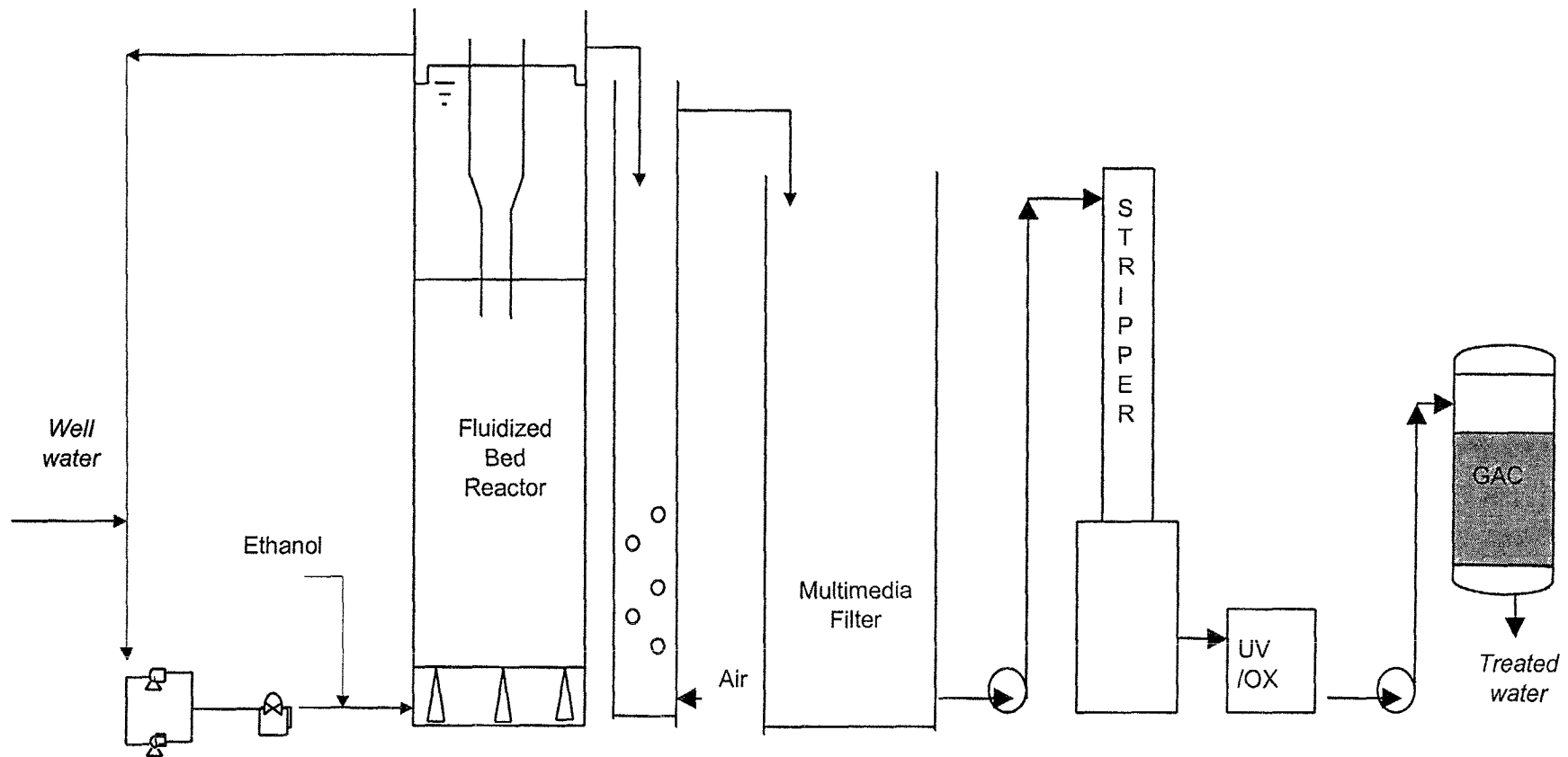


Results - RDX Mass Balance

Phase 2						
	Average RDX Concentrations (ug/L)	Calculated Mass of RDX Removed from Water by FBR During Phase (ug)	Measured Mass of RDX In GAC at Beginning of Phase (ug)	Measured Mass of RDX In GAC at End of Phase (ug)	Mass of RDX Degraded During Phase (ug)	% of RDX Degraded During Phase (ug)
FBR 1 Acetic Acid Effluent GW Feed	2 190	128,813	128,000	1,200	255,613	99.5
FBR 2 Molasses Effluent GW Feed	4 193	129,548	264,000	236,000	157,548	40.0
FBR 3 Control Effluent GW Feed	2 190	128,863	248,000	312,000	64,863	17.2



5 Process Train Accepted by DHS



Operating & Maintenance Costs Aerojet Facility, Rancho Cordova

	Annual Cost			Cost Per Acre-Foot		
	<u>3600 gpm</u>	<u>5000 gpm</u>	<u>6000 gpm</u>	<u>3600 gpm</u>	<u>5000 gpm</u>	<u>6000 gpm</u>
Additives	\$50,000	\$69,000	\$83,000	\$9	\$9	\$9
Power	86,000	107,000	119,000	15	13	12
Labor	90,000	90,000	90,000	15	11	9
Sludge Disposal	75,000	109,000	131,000	13	14	14
Other	<u>50,000</u>	<u>70,000</u>	<u>80,000</u>	<u>9</u>	<u>9</u>	<u>8</u>
Total	\$351,000	\$445,000	\$503,000	\$61	\$56	\$52

Notes:

- Based on data taken from 6/99 to 2/03
- Conc. of perchlorate – 2 to 6 ppm
- Labor includes 3 part-time personnel
- Costs include all O&M associated with the FBR including solids filtration.



FBR Summary

- Biological Fluid Bed Reactors (FBRs) successfully treating more than ~~76.0~~ 76.0 million gallons per day of groundwater containing perchlorate
- Consistent effluent perchlorate levels below current practical quantitation limits (4 $\mu\text{g/L}$)
- Single FBR will treat from 50 to 2,000 gallons per minute
- No flow rate limits with multiple units
- Recent acceptance by CA DHS for use in drinking water product